LA-UR -84-339

CONF-840249--1

LA-UR--84-339

DE84 006028

TITLE: NONLINEAR OPTICS: WHERE DO WE GO FROM HERE?

AUTHOR(S): Robert A. Fisher

SUBMITTED TO: Proceedings of NSF Workshop "The Future of Lightwave Technology"
University of Southern California, Los Angeles, California
February 1, 1984.

NONLINEAR OPTICS: WHERE DO WE GO FROM HERE?

Robert A. Fisher
Los Alamos National Laboratory
Los Alamos, NM 87545

Classical optics texts tell us that <u>linear</u> <u>optics</u> is the study of camera lenses, telescopes, microscopes, diffraction gratings, spectrometers, and effects such as diffraction, dispersion, absorption, optical gain, etc. The underlying feature of all the above associated processes is that the response of the system involves a polarization which is <u>strictly</u> proportional to the applied optical fields. In all of these linear systems, two inputs cannot couple together to generate a new wave which would not have been present as a response to either <u>single</u> input.

<u>Nonlinear optics</u> can be described as "none of the above" in the formal sense that the subject deals with induced polarizations which are <u>not</u> proportional to the input fields. This topic includes the spontaneous scattering of light waves by elementary excitations such as sound waves, plasma waves, heat waves, molecular vibrations (the Raman effect), spin waves, and a host of others; such spontaneous scatterings do not rely on the brightness of the probe light source, and therefore many of these topics were understood well before the invention of the laser. The laser did herald a new age, however. Now materials can be exposed to optical intensities exceeding 10^{15} Watts per square centimeter, with pulse durations ranging from femtoseconds (10^{-15} seconds) to several hours. Additionally, the spectral bandwidths of the exciting light can be made exceedingly narrow and exceedingly directional.

Nonlinear optics has brought us numerous benefits, including saturation spectroscopy (how atoms and molecules behave in intense fields), Brillouin, Raman, and Rayleigh spectroscopy (to study sound waves and other excitations in materials, especially near their critical points), materials processing (such as annealing, welding, ion implanting, photolithography, etc.), optical diagnostics (for studying chemical reactions), laser-fusion (for the initiation of laboratory-scale thermonuclear reactions), saturable absorbers (devices whose transmission depends upon input intensity), laser isotope separation (for enrichment of nuclear fuels), efficient extraction of the energy stored in a laser amplifier, frequency doubling and tripling (to produce light at otherwise unobtainable frequencies), parametric generation of new frequencies, optical phase conjugation (the conversion of an input beam to its conjugate providing real-time adaptive optics correction for arbitrary distortions, pulse compression, and devices for all-optical computations. From the variety of topics described in other presentations here yesterday and today, it is easy to see that this list is far from complete. Unfortunately, nonlinear optics can also be an obstacle to many projects. Such is the case with self-focusing (the collapse of a strong beam as it propagates), damage, plasma formation, thermal blooming, and spectral broadening. These detrimental aspects are always essential to understand because they always limit the intensity which one can propagate through a given optical system.

An example of the great wealth of information which nonlinear optics can provide, let us consider the example of the light scattering spectrum from a simple liquid. The width of the central (or Rayleigh) peak gives us the thermal conductivity, the separation of the two sidelobes gives us the speed of sound at a given frequency, the ratio of the heights of the sidelobes to the central peak gives c_p/c_v (the ratio of specific heats at constant pressure and constant volume) and the width of the sidelobe gives the sum of the shear modulus and the bulk modulus. Examination of several such spectra at different temperatures near the material's critical point can provide fundamental scaling laws associated with phase transitions.

Nonlinear optics is unique in that it is often not perceived as a separate discipline. It overlaps the fields of chemistry, the physics of liquids, solid-state physics, atomic physics, molecular physics, etc. For this reason, efforts in nonlinear optics are often hard to uniquely categorize. The American Physical Society, for example, does not yet have a division dedicated to nonlinear optics or quantum electronics, thereby distributing the effort among the above-named traditional disciplines instead of giving it the focus it deserves.

To me, a more appropriate approach would be to accept nonlinear optics as a field and to understand its underlying interdisciplinary aspects. A researcher in nonlinear optics has to call upon a working knowledge of many fields. There are too many examples in nonlinear optics where significant discoveries are unusually (and unsuspectingly) linked to other fields. Examples of this are:

1. The nonlinear processes of photodissociation and time-resolved CARS (Coherent Anti-Stokes Raman Spectroscopy) are now routinely used[1] to examine formerly unavailable information concerning photodissociation chemistry and $H + D_2$ reaction chemistry.
2. The theoretical study of self-steepening[2] in dispersionless Kerr-like media can in retrospect be related to similar developments in theoretical astrophysics.[3]

3. Raman-induced ionization spectroscopy,[4] although utilizing highly nonlinear phenomena, is motivated by the possibility of obtaining novel molecular spectra.
4. Optical phase conjugation[5] converts an input beam to its "conjugate" with its unique and useful image-transformation properties. This provides and instantaneous automatic real-time adaptive optic correction for random distortions. Optical phase conjugation has many striking similarities to holography, yet it utilizes almost any nonlinear optics effect (Brillouin, Raman, Rayleigh wing scattering, photon echoes, four-wave mixing, etc.). One surprise side-effect of this work is that optical phase conjugation might lead to a means of producing a two-photon coherent state, an eigenstate of a squeeze operator. Such a state promises to be of use[6] in reducing below the "naive" quantum limit the noise of a gravitational wave detector. It is also very tantalizing to note that the coupled wave equations of degenerate four-wave mixing (a relatively popular form of optical phase conjugation) are very closely related to current models of the neurophysiological response.[7]
5. Recently discovered optical solitons and their implementation in the soliton laser[8] involve special solutions of the nonlinear Schrodinger equation; these solutions apply equally well to plasma physics, superconductivity, low-temperature physics, water waves, and vortex motion.[9]

These few selected examples of interdisciplinarity to me indicate that support of nonlinear optics can lead to developments in a host of other disciplines. No amount of planning can anticipate where and how these contributions will be made. For these reasons, nonlinear optics deserves support on its own right instead of in the narrower context of trying to fit portions of it into each of the the more traditional disciplines. This should be done with full knowledge that nonlinear optics will contribute heavily to other disciplines.

References:

1. J. J. Valentini, Chem. Phys. Lett. 96, 395 (1983); D. P. Gerrity and J. J. Valentini, J. Chem. Phys. 79, 5202 (1983).

2. F. DeMartini, C. H. Townes, T. K. Gustafson, and P. L. Kelley, Phys. Rev. 164, 312 (1967).

3. M. Lutzky and J. S. Toll, Phys. Rev. 133, 1649 (1959).

4. A. Owyoung, Sandia Laboratories, private communication.

5. See, for example, R. A. Fisher, ed., Optical Phase Conjugation (Academic, New York, 1983).

6. See, for example, C. M. Caves, Phys. Rev. D 23, 1693 (1981).

7. Marcus S. Cohen, Department of Mathematics, University of Kentucky, "Interacting Nonlinear Waves in a Neural Continuum Model: Associative Memory and Pattern Recognition," to appear in Wave Phenomena, Modern Theory and Applications (North Holland).

8. L. F. Mollenauer and R. H. Stolen, Opt. Lett. 9, 13 (1984), and references therein.

9. G. B. Whitham, Linear and Nonlinear Waves (Wiley, New York, 1974); K. Lonnegren and A. Scott, eds., Solitons in action (Academic, New York, 1978).